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A COMPARATIVE STUDY OF RAINGAGES

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The rain gage may be termed the basic instrument of the hydrologist because it should provide the means of answering his first question: How much water is there to deal with? This quantity must be known before subsequent questions relating to infiltration, stream-flow, ground water, et al. may be answered. It is recognized of course that snow forms an important source of water, but this paper will deal only with precipitation in the form of rain. The conventional rain gage consists of a sharp-edged collecting ring, the receiver, made to an accurate diameter of eight inches, a collector can, and a support, the assembly having a total height of about 40 inches. When it is set up, the gage is plumbed carefully so that the rim of the receiver is horizontal. Exposed in this manner a rain gage should sample rainfall perfectly if it is set on level ground and the rain is falling straight down. These ideal conditions are practically never realized, especially when the sampling is being carried out in mountainous regions where wind movement is violent and changeable.

These conditions prevail on the San Dimas Experimental Forest[5] in southern California where the accurate measurement of the volume of water precipitated on the steep mountain slopes is essential to the watershed management investigations being conducted on this area by the Forest Service. This is being accomplished by sampling rainfall through an extensive and intricate network of standard rain gages distributed over an area of

17,000 acres. The number and the distribution of the gages were determined and checked by a statistical analysis that has been described in a previous publication~~[10]~~[11]. This analysis showed that the method of sampling was sufficiently accurate for the end in view, providing the samples themselves were accurate.

It should be interjected at this point that none of the rain gages on the Experimental Forest have ever been shielded. It was believed that sufficient natural protection against wind movement would be afforded by the location of the gages in openings within the chaparral cover of the mountain slopes.

In order to test the accuracy of the 8-inch gage in sampling rainfall at any one locality, two studies were initiated on the San Dimas Forest. The first has been completed and described in a paper entitled "An Analysis of Precipitation Records from Standard Rain Gages--Vertical and Tilted"~~[9]~~[10]. Here in one small watershed 22 paired 8-inch gages were installed; at each location one gage was placed vertically and the other normally to the ground surface. Analysis of measurements from these gages showed a significant difference in that those which were tilted normally to the slope gave consistently higher readings than those exposed vertically.

The second study, which is discussed in the following pages, tested not only the 8-inch gage installed vertically but also the result of tilting the gage and lowering it near and to the ground surface. Several other types of gages were also compared with controls and the conventional gage. The effect of shields was not considered in this study, as it was desired to study the gages per se.

Experimental Procedure

Since it was essential to obtain a good measure of the actual amount of precipitation that reaches the slopes, three circular concrete surfaces were installed to serve as controls in the study. These surfaces were 10 feet in diameter, laid flush with the ground surface and parallel to the slope. Each was provided with a metal border strip to serve as a sharp cutting edge. The surfaces were installed near the top of a small hill (see map and profile, Figs. 1 and 2), each on a different exposure, one facing east, one south, and the other northwest. The catch of each concrete surface was measured in catchment tanks and was assumed to be a close measure of rainfall actually landing on the earth in the immediate vicinity of the surface.

Immediately adjacent to each surface, gages were installed in the following manner (Figs. 3 and 4):

1. Standard 8-inch gage set vertically and at the height above ground prescribed by Weather Bureau practice.

2. Standard 8-inch gage tilted normally to the ground surface and at conventional height. This type of exposure follows the recommendation by Pagliuca[6], though omitting the shield.

3. Standard 8-inch gage tilted normally to the ground surface and set in a pit so that the top of the funnel was 1 foot above ground. The recommendation of the British Meteorological Office was followed here with the exception that the gage was tilted normally to the ground slope.

4. Standard 8-inch gage tilted normally to the ground surface and set in a pit so that the top of the funnel was flush with the ground; the adjacent ground surface was covered with brush cuttings to

prevent splash into the gage. Here the installation was designed to combine the features of (2) and (3) to the best advantage.

5. Standard 8-inch gage set vertically in a pit so that the top of the funnel was flush with the ground surface; ground surface covered with brush cuttings to prevent splash into the gage[4/2/9]. This is the good old pit gage that has been the subject of research by many investigators for nearly a century.

6. 8-inch gage of standard height equipped with a funnel that was cut on a bias so that the opening presented an ellipse in the plane of the ground surface and an 8-inch circle on a horizontal plane. This unusual gage was designed in an effort to combine the effect of a tilt on a standard type of gage with its ordinary performance. It is called a "stero rain gage" after the design suggested by Pers[7] and further recommended by Boutaric[1]. However, the construction of the receiver has been simplified from that proposed by Pers to simple circular and elliptic forms rather than a projection of the area whose rain catch it was designed to sample. A gage of this type has also been designed and used by Hayes in northern Idaho.[3]

7. Trough-type gage, which consists of a trough having a rectangular plane and a semicircular cross section. The trough is 9 inches wide and is installed parallel to the slope. A sliding cover plate makes it possible to adjust its length so as to expose a constant projectional area of 220 square inches regardless of the slope on which the gage is set. Rainfall is measured in tanks connected to the trough. So far as the authors have been able to determine, the trough type of rain gage was first designed by Dr. W. C. Lowdermilk and installed in 1929 at the Devil Canyon Branch of the California Forest and Range Experiment Station in southern California.

prevent splash into the gage. Here the installation was designed to combine the features of (2) and (3) to the best advantage.

5. Standard 8-inch gage set vertically in a pit so that the top of the funnel was flush with the ground surface; ground surface covered with brush cuttings to prevent splash into the gage. This is the good old pit gage that has been the subject of research by many investigators for nearly a century.

6. 8-inch gage of standard height equipped with a funnel that was cut on a bias so that the opening presented an ellipse in the plane of the ground surface and an 8-inch circle on a horizontal plane. This unusual gage was designed in an effort to combine the effect of a site on a standard type of gage with its ordinary performance. It is called a "stereo rain gage" since the design suggested by Pers and further recommended by [illegible]. However, the construction of the receiver has been simplified from that proposed by Pers to simple circular and elliptic forms rather than a projection of the area which rain which it was designed to sample. A view of this [illegible]

7. Trough-type gage, which consists of a trough having a rectangular plane and a semicircular cross section. The trough is 9 inches wide and is installed parallel to the slope. A sliding cover piece makes it possible to adjust its length so as to expose a constant projectional area of 100 square inches regardless of the slope on which the gage is set. Rainfall is measured in a gage connected to the trough. So far as the authors have been able to determine, the trough type of rain gage was first designed by Dr. H. G. Wilm-[illegible] and installed in 1937 at the Devil Canyon branch of the California Forest and Range Experiment Station in southern California.

8. Four-inch gage placed vertically, its receiver the same distance above the ground as the standard 8-inch gage.

The catch of each gage and each control surface was measured shortly after each storm. All readings for each gage and surface were converted to the equivalent readings on a horizontal plane. This placed all readings on the same basis and made the measurements applicable to horizontal areas as measured on maps.

On the crest of the hill adjacent to the rain-gages and the surfaces were installed a wind-direction transmitter, an anemometer, and a tipping-bucket rain-gage, all recording. The installation also included a directional rain-gage (Fig. 3) that measured the amount of rain coming from each cardinal direction as well as the average angle at which it fell. This instrument is called a Vectopluviometer. It was constructed, although in modified form, after an instrument designed by Robert Pers[8], a professor at the University of Grenoble in France.

Results

Since this study was designed to compare the catch of the different gages with the concrete control surfaces, the former have been plotted as functions of the latter (Fig. 7). The line of equal catch was indicated, as well as the regression line for the points plotted. Regression coefficients were computed and tabulated according to exposure and type of gage (Table 1). Examination of this table and the graph (Fig. 7) shows that the 8-inch standard gage has a mean regression coefficient of .9704, that of the 8-inch gage placed vertically at ground level is .9773 while the 4-inch gage is considerably lower with .9481. The coefficients of all the other gages are equal or slightly higher for south and east exposures and slightly lower for northwest exposures. In the case of the trough gage, the regression coefficient of .8911 appeared to be inconsistent compared with 1.0020 and 1.0076 for the other two exposures. An examination of the installation revealed that a small tree had increased in height growth so much as to interfere with

with the catch of the gage. Because of this, data for the gage have been plotted and tabulated both with and without those from the northwest exposure.

The average deviations of catches in the various types of gages from those of the concrete surfaces were computed and arranged according to exposure, type of gage, and size of storm (Table 4). Perusal of this table shows that the catch of the trough gage is consistently nearest to that of the control surfaces, if the northwest exposure be omitted for reasons mentioned above. The other gages do not show very great deviations from the concrete surfaces with the exception of the [illegible] gage. Its percentage of deviation is consistently high.

Conclusions

In the course of this study a number of interesting points have been brought out. It has been shown that rainfall measurements made with the standard 8-inch rain gage are consistently low. However the accuracy of the standard gage can be increased by tilting it normal to the slope. The lowering of a gage to the ground level will further improve its accuracy but not enough in [illegible] to warrant the great amount of work required for many gages. The trough gage is inadequate for such measurements as pointed out by [illegible], and another serious disadvantage is that it may be interfered with by animals. The gage [illegible] sunk in the ground as advocated by the British Meteorological Office partially meets the latter two objections but is still subject to the first disadvantage as above. The stereo rain gage gives good results but this study has shown it to be no more accurate than the standard tilted gage; and it is more expensive to construct. Also its measurements are inferior to the tilted gage, as has been pointed out by [illegible]. In his experiments with this type of gage he also encountered [illegible] difficulty.

Table 1. Summary of regression coefficients for all gages plotted against concrete surfaces.

Type of gage	Regression coefficients by exposures			
	East	South	North-west	Mean
1 - Standard 8"	.9889	.9550	.9571	.9704
2 - Tilted '8"	1.0115	1.0256	.9644	.9987
3 - Tilted 8" 1 ft. high	1.0198	1.0130	.9457	.9906
4 - Tilted 8" at ground	1.0073	1.000	.9799	.9951
5-- Vertical 8" at ground	.9974	.9704	.9681	.9773
6 - Stereo	1.0220	1.0226	.9684	1.0020
7 - Trough	1.0020	1.0076	.8911	.9617 a/ 1.0046 b/
8 - 4" vertical	.9831	.9299	.9312	.9481

a/ Using all three exposures

b/ Northwest exposure omitted

Table 2. Average deviations in percent of various types of gages from control surface readings, arranged by type of gage, exposure, and class of storm[a].

Type of gage	East exposure			South exposure			Northwest exposure			All exposures		
	Class of storm[a]											
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
	Percent											
1 - Standard	4.8	2.4	2.5	10.0	5.9	6.4	12.8	7.7	4.4	9.2	5.4	4.4
2 - Tilted	6.8	2.7	2.9	10.7	4.3	2.2	15.9	3.6	4.6	10.9	4.1	3.3
3 - Tilted 8" 1 ft. high	6.9	3.6	4.1	11.0	4.0	2.2	15.2	9.3	5.2	10.9	5.6	3.9
4 - Tilted 8" at ground	5.5	4.3	2.9	8.6	3.3	2.0	11.0	8.0	3.7	8.5	5.2	2.9
5 - Standard at ground	6.2	2.7	2.7	9.3	3.2	4.9	12.4	6.1	3.3	9.2	4.0	3.6
6 - Stereo	10.0	4.3	4.4	10.3	4.7	3.6	12.8	5.6	3.9	10.9	4.8	4.0
7 - Trough	5.2	3.2	1.4	7.6	3.7	1.9	17.9	16.3	10.6	10.2 6.4	7.8 3.4	5.0[b] 1.6[c]
8 - 4"	10.3	7.5	3.3	17.6	10.7	7.0	24.4	9.9	6.5	17.4	9.4	5.6

a/ Classes of storms: X = between 0 and ½ inch of rainfall
Y = between ½ and 1 inch of rainfall
Z = over 1 inch of rainfall

b/ Averages of all three exposures

c/ Averages of east and south exposures

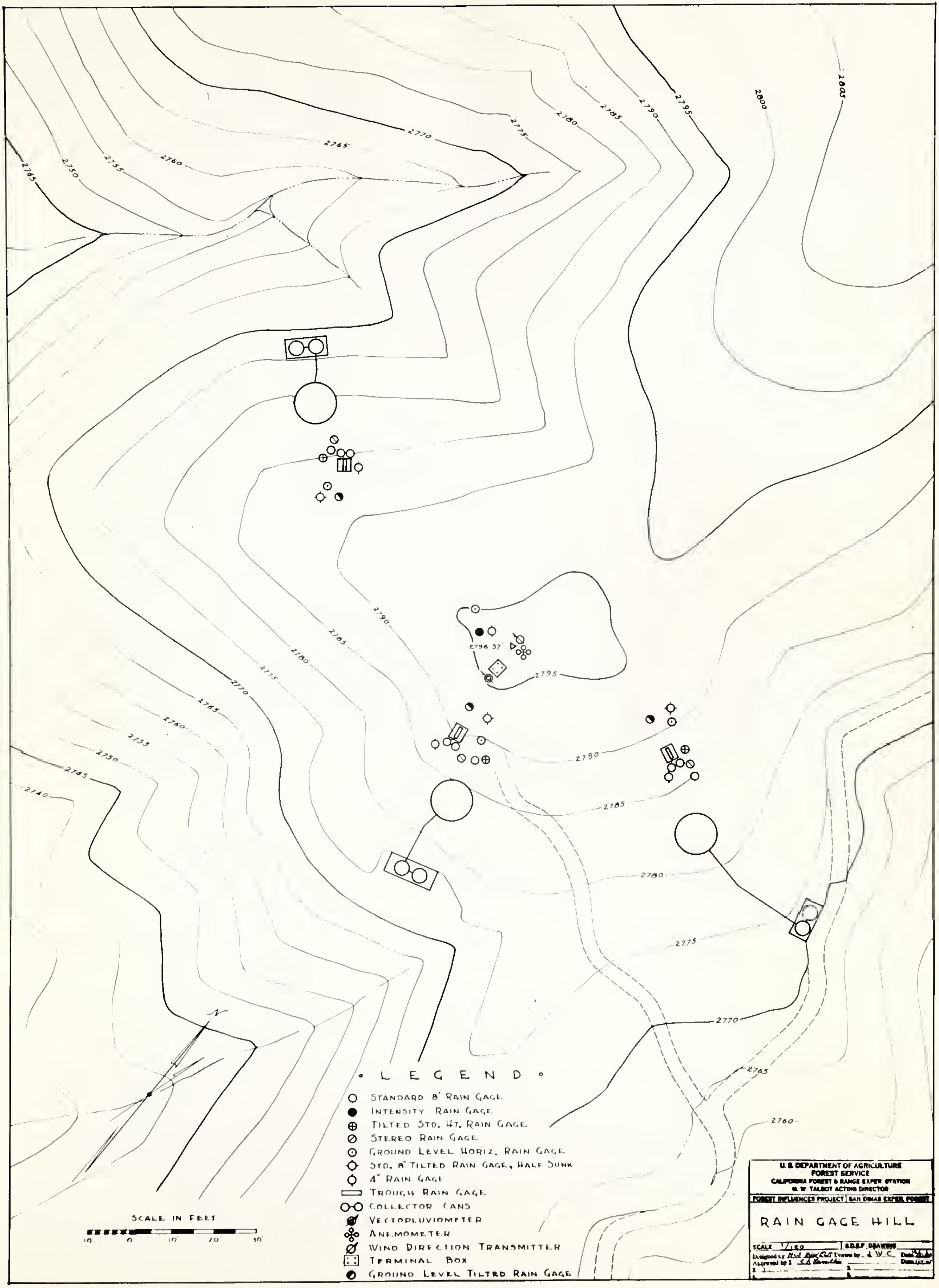
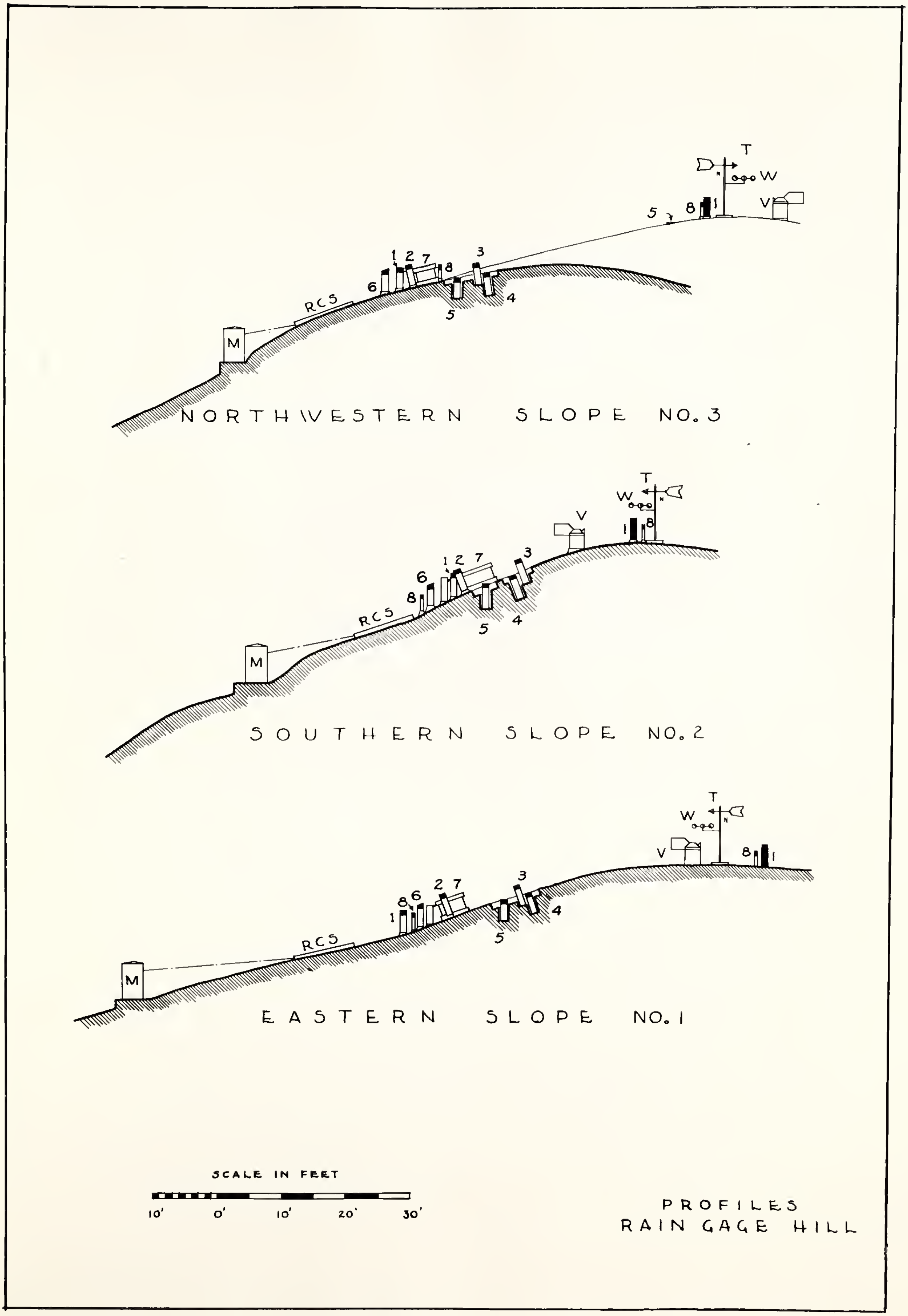


Figure 1--Rain Gage Hill

figure 1

Figure 2. Rain Gage Hill Profile

1. Standard 8-inch rain gage. 2. Tilted 8-inch rain gage. 3. Tilted 8-inch gage, half sunk. 4. Tilted 8-inch gage sunk to ground level. 5. Vertical 8-inch gage sunk to ground level. 6. Stereo rain gage. 7. Trough rain gage. 8. 4-inch rain gage. T. Wind direction transmitter. W. Anemometer. I. Intensity rain gage. V. Vectopluviometer. RCS. Rain catchment surfaces. MM. Collector tanks.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SOUTHERN SLOPE NO. 2
EASTERN SLOPE NO. 1
SCALE IN FEET
10' 0' 10' 20' 30'
PROFILES
RAIN GAGE HILL

Figure 2.

Figure 2

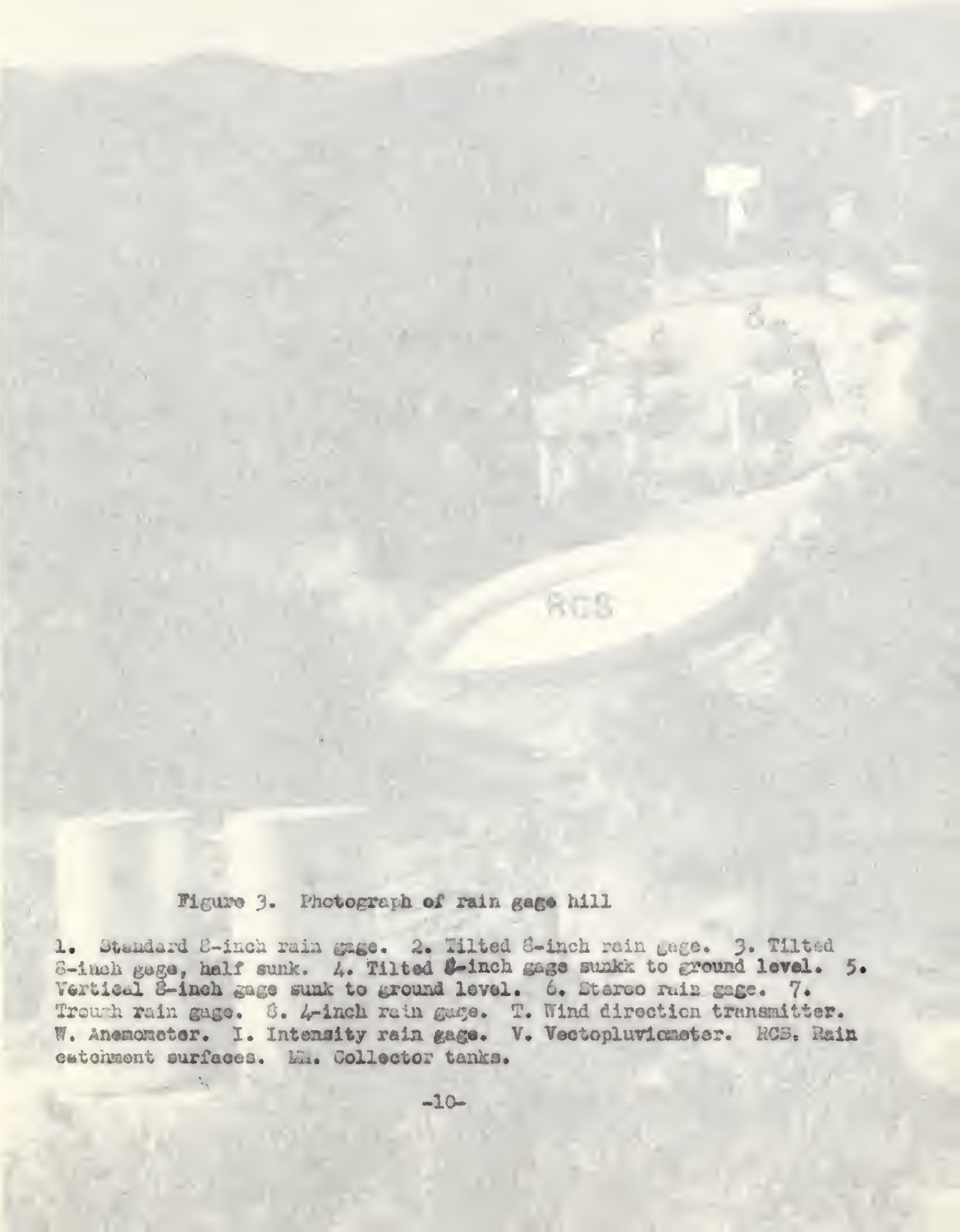

Figure 3. Photograph of rain gage hill

1. Standard 8-inch rain gage. 2. Tilted 8-inch rain gage. 3. Tilted 8-inch gage, half sunk. 4. Tilted 8-inch gage sunkk to ground level. 5. Vertical 8-inch gage sunk to ground level. 6. Stereo rain gage. 7. Trough rain gage. 8. 4-inch rain gage. T. Wind direction transmitter. W. Anemometer. I. Intensity rain gage. V. Vectopluviometer. RCS. Rain catchment surfaces. MM. Collector tanks.


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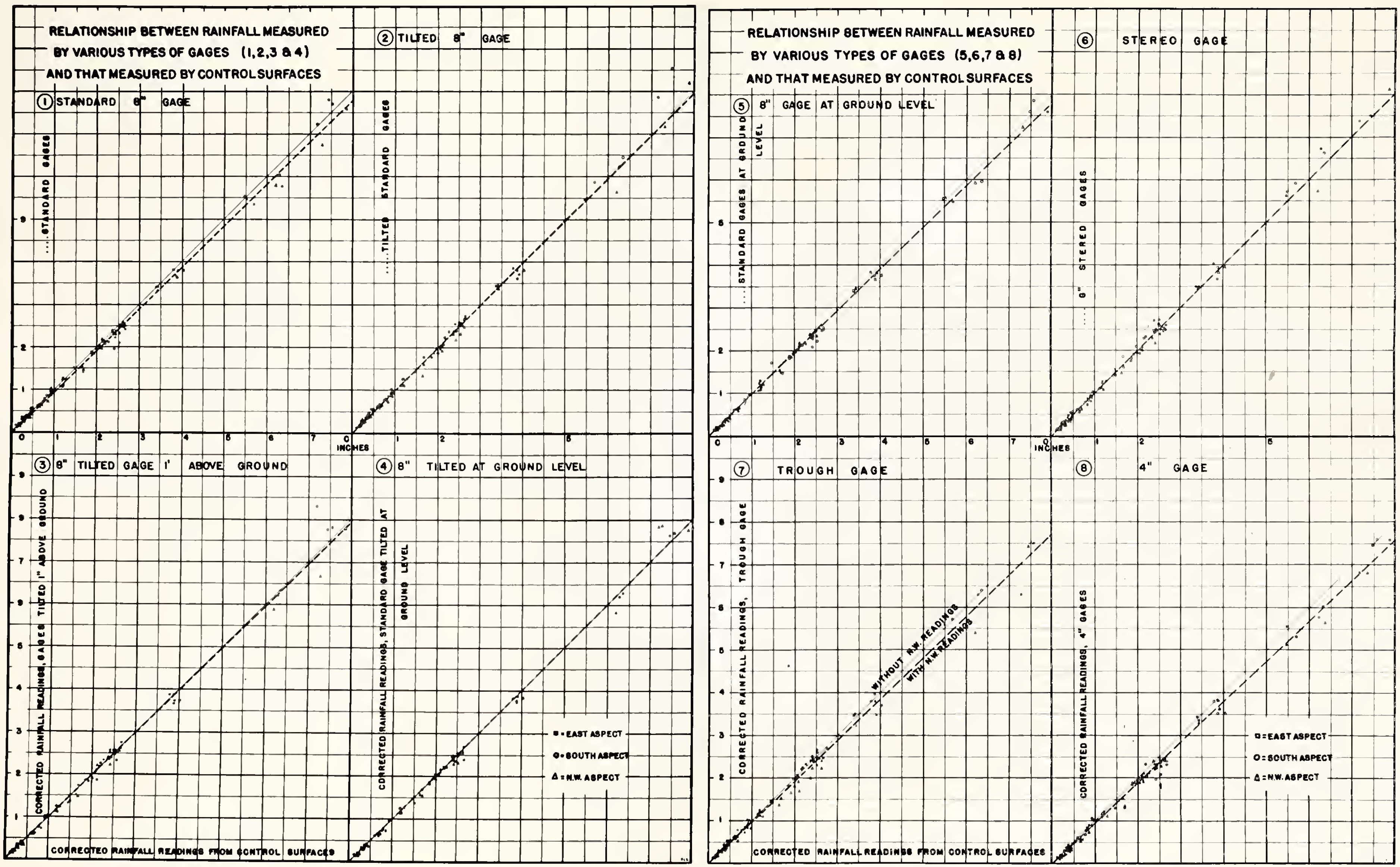
RELATIONSHIP BETWEEN RAINFALL MEASURED BY VARIOUS TYPES OF GAGES (1,2,3 & 4) AND THAT MEASURED BY CONTROL SURFACES
① STANDARD 8" GAGE
....STANDARD GAGES
② TILTED 8" GAGE
....TILTED STANDARD GAGES
③ 8" TILTED GAGE 1' ABOVE GROUND
CORRECTED RAINFALL READINGS, GAGES TILTED 1" ABOVE GROUND
④ 8" TILTED AT GROUND LEVEL
CORRECTED RAINFALL READINGS, STANDARD GAGE TILTED AT GROUND LEVEL
■ = EAST ASPECT
● = SOUTH ASPECT
Δ = N.W. ASPECT
INCHES
CORRECTED RAINFALL READINGS FROM CONTROL SURFACES
RELATIONSHIP BETWEEN RAINFALL MEASURED BY VARIOUS TYPES OF GAGES (5,6,7 & 8) AND THAT MEASURED BY CONTROL SURFACES
⑤ 8" GAGE AT GROUND LEVEL
....STANDARD GAGES AT GROUND LEVEL
⑥ STEREO GAGE
....8" STEREO GAGES
⑦ TROUGH GAGE
CORRECTED RAINFALL READINGS, TROUGH GAGE
WITHOUT N.W. READINGS
WITH N.W. READINGS
⑧ 4" GAGE
CORRECTED RAINFALL READINGS, 4" GAGES
□ = EAST ASPECT
○ = SOUTH ASPECT
Δ = N.W. ASPECT
INCHES
CORRECTED RAINFALL READINGS FROM CONTROL SURFACES

Figure 5

Figure 5

Figure 4--Close view of gages

The trough rain gage gives an excellent measure of rainfall but again its construction is somewhat intricate and fairly expensive, and furthermore it is unsuitable in the case of snow. However, in mountainous situations where an accurate measure of <u>rain</u> from a single gage is desired, the trough rain gage is highly recommended. The 4-inch gage is not recommended where it is desired to obtain reliable and consistent measurements.

Results obtained from measurements at this installation are indicative of trends but are probably conservative as to quantity. The comparison of vertical and tilted gages mentioned previously[8] indicates that more extreme differences may be obtained out in the watersheds.

The writers feel that the question of tilting the standard rain gage is an important one. They recommend to the committee on rainfall of the American Geophysical Union that a new standard practice with regard to rain gage exposure be considered wherein all gages installed for hydrologic use be exposed normally to the ground slope at the site of the instrument.

Acknowledgment is made to the Glendora Civilian Public Service Camp No. 76 for assistance in the presentation of this paper, and especially to John A. Ohlson, of the camp, who made the statistical analysis.

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